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Manufacturing of a Composite Tailcone for an XM-1002 Training Round

by James M. Sands, Uday Vaidya, George Husman, Juan Serrano, and Robert Brannon

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14. ABSTRACT
Recent work on the cost-effective manufacturing of an extrusion-compression molded, long-fiber thermoplastic (LFT) XM-1002 tailcone for training rounds of military ammunition is compiled in this technical report. During the last decade, the engineering community has expanded the use of thermoplastic composites due to their inherent advantages over traditional thermoset composites including: high toughness, inexpensive resin systems, short processing cycle times, recycling potential, excellent environmental resistance, and damage tolerance. Thermoplastic composites have a wide range of applications in the automotive and transportation industry for replacement of heavy metal components and/or structures. LFT composites are a family of compounds with reinforcing fiber strands (fiber lengths typically range from 6 to 24 mm) combined with a thermoplastic matrix (which can be any commodity or engineering thermoplastic polymer). LFTs have the ability to be molded into complex geometries featuring ribs, knock-outs, and thickness variations within the parts. LFT parts/components can be processed by extrusion-compression, injection-compression, and/or injection-molding processes.

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long fiber thermoplastics, compression molding, resins/materials – thermoplastics, applications – military, XM-1002, manufacturing, composite

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1. Thermoplastic Composite Manufacturing

Long fiber-reinforced thermoplastics (LFTs) have received a lot of attention in the automotive industry due to the improved mechanical properties that can be achieved and the relative ease of fabrication and handling of these materials (*1*). The global use of LFTs is expected to grow from around 18 million kg (40 million lb) in 2001 to 34 million kg (75 million lb) in 2007 (*2*). Long fibers (fiber lengths between 12 and 50 mm) provide elastic modulus and the tensile strength close to 90% of that obtained using continuous fibers (*3*) (figure 1). The main advantage of LFTs is that unlike continuous fiber reinforced composites, they can be processed using traditional plastics molding equipment and therefore parts can be manufactured at medium volume rates with excellent consistency and repeatability. The use of a thermoplastic matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers, and fire retardants depending on the nature of the application (*4*).

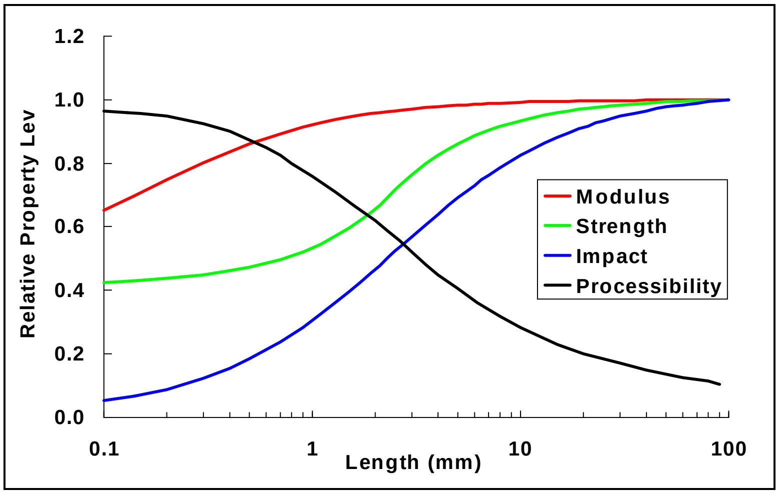

Figure 1. Effect of glass fiber length on composite properties (*3*).

LFTs can be manufactured using conventional extrusion-compression molding and/or injection-molding techniques. Most of the applications in which LFTs have been commercialized include a polypropylene (PP) matrix and E-glass fiber reinforcement. In the last few years, there have been interesting innovative developments focused on automation of these processes that increase the output rate, such as D-LFT, S-LFT and E-LFT (*1*). Variations of these processes have also been used to produce sheets starting with neat resins and fiber rovings (*4*). Advances have also led to the utilization of a wide variety of engineering thermoplastics as matrix materials along with other fiber reinforcements (*2*).

Compression molding is an established composite-processing technique which was originally developed for the stamping of thermoset matrix composite pre-impregnated sheets to complex geometries. In this process, a pre-impregnated sheet molding compound (SMC) is heated to its softening point, and then transferred to a compression-molding press, where the sheet is formed using double-sided tooling (aluminum, steel, or epoxy). The important feature of this process is that during forming, the material is not subjected to high levels of stress as in injection molding, and therefore the reinforcement is not damaged (*5*). In the case of LFT-compression molding, the process begins by hot-melt impregnating reinforcing fibers with a thermoplastic matrix and subsequently chopping the continuous tow into pellets of a set length (between 8 and 50 mm) (figure 2). Hot-melt impregnation is performed by wire coating, crosshead extrusion, and/or thermoplastic pultrusion (*3*). The long fiber pellets are fed into the hopper of a single-screw, low-shear extruder. A molten charge of a predetermined size and shape (usually cylindrical) is extruded, which is then transferred by an operator (or a robot) to the compression-molding press for the forming operation (figure 3).

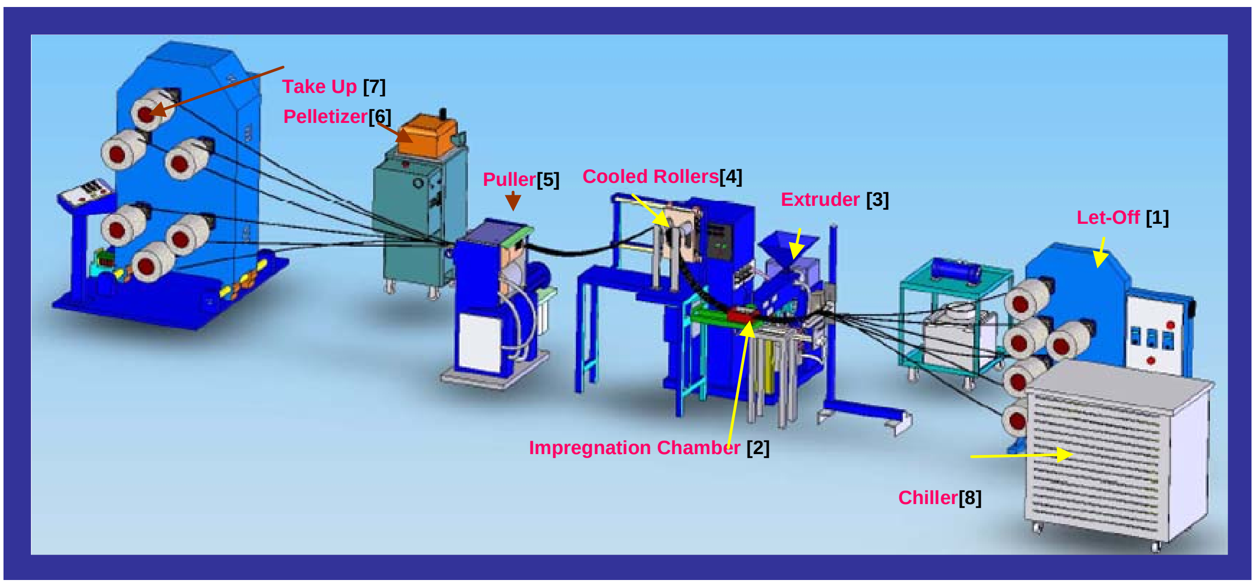

Figure 2. Hot-melt impregnation line for production of thermoplastic composite pellets and tape (courtesy: National Composite Center).

Cycle times for this process can be as short as one part per minute, and the production rate can be accelerated by utilizing multiple cavity tools. The extrusion-compression molding is ideal for small-to-medium sized semi-structural components for the automotive industry and has already been implemented in applications such as automotive side panels, bumper beams, dash boards, underbody panels, and hoods. The potential for using thermoplastic LFT technology in other applications such as military components, infrastructure and aerospace is expanding due to the cost-effective nature of the resins and processing methods.

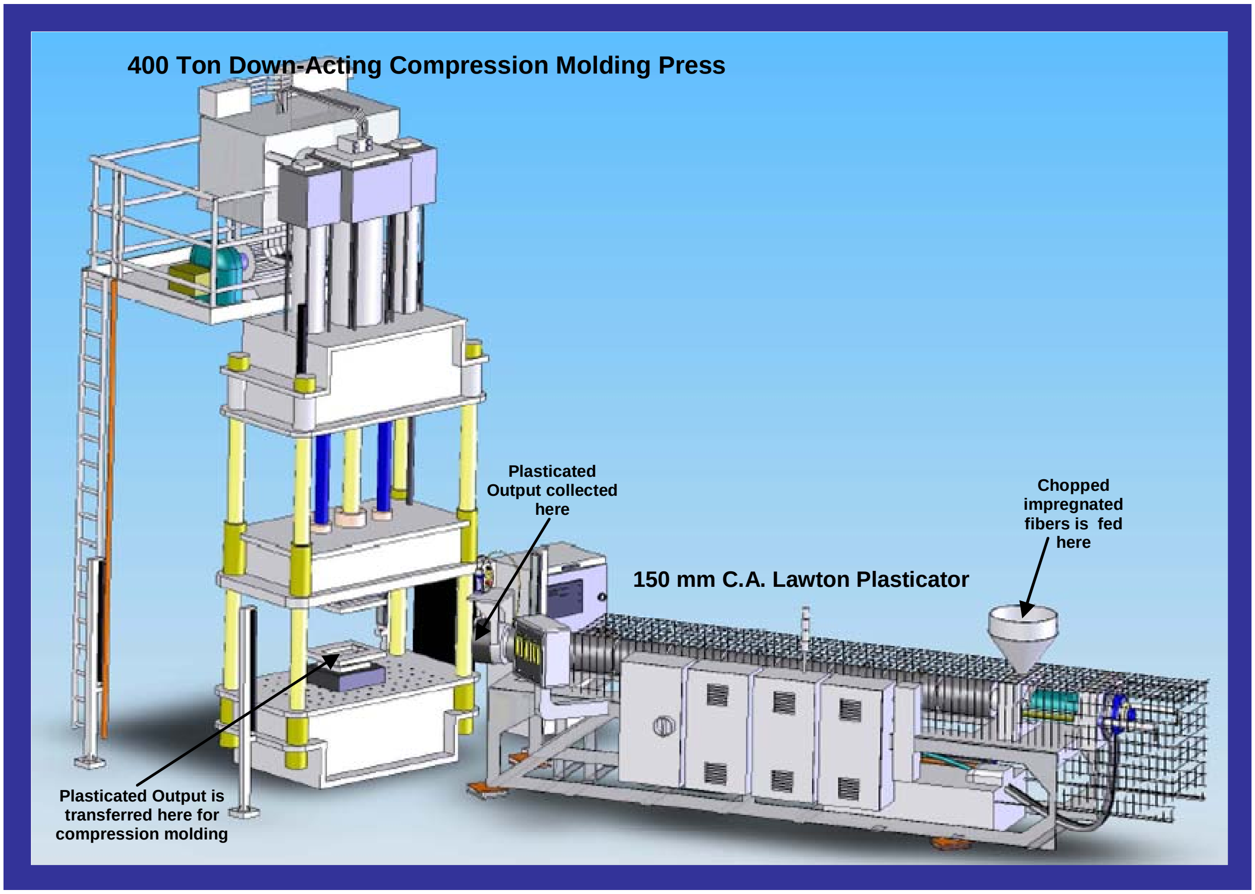

Figure 3. Extrusion compression molding line for LFT (courtesy: National Composite Center).

2. Kinetic-Energy Penetrator

A kinetic-energy (KE) penetrator is one of the ammunition types used by the military as the main ammunition on tanks. A KE projectile is comprised of three parts: (1) the nosecone, tailored for aerodynamics and penetration; (2) the projectile mass rod, where most of the projectile's mass is concentrated to achieve a high KE during impact; and (3) the tailcone, which is aerodynamically designed to induce drag and stabilize the projectile by inducing rotation. In the field, the stabilizer used in the KE projectile includes a finned assembly, but, in the case of training rounds, the use of fin-stabilized rounds is not required. Instead, a grooved stabilizer made of machined aluminum is used. The projectile is encapsulated in a shell and it is fired by the combustion of a propellant inside the chamber (*6*).

The use of a plastic tailcone for a KE penetrator training round was investigated by Garner et al. (*7*). From this study, it was evident that by manufacturing the tailcone using a conventional plastic processing route such as injection molding, significant cost savings could be achieved when compared to an aluminum-machined tailcone that is currently used. Studies by Garner

et al. (*7*) also demonstrated that select commercial polymers could withstand the extreme conditions witnessed during firing inside the barrel, and the pressure drop during the muzzle exit of the projectile. However, the cost of the proposed polymer resins (poly ether ether ketone [PEEK]) in their study is relatively high and currently runs about $96/kg ($44/lb) (*8*). In this study, the manufacturing of a thermoplastic composite tailcone made of nylon66/glass LFT is discussed. The focus of this work is to demonstrate the feasibility of producing a thermoplastic tailcone that is both cost-effective and easy to process in a medium-volume production environment.

3. Material Selection

Several high-performance materials have been investigated for use in a training projectile for military ammunition. Both thermoset and thermoplastic polymers, fiber-reinforced, and unreinforced polymers have been field tested under high pressures and accelerations experienced during firing of the projectile with mixed results (*9*). The extreme loading conditions witnessed by the sub-components inside the bore and in the transition loads at the muzzle end must be taken into account during the material selection process. A detailed finite-element analysis (FEA) based study was conducted (*10*) based upon which long-fiber-reinforced polyamide (nylon (w_F = 10%, and w_F = 40%) was chosen for this application.

4. Manufacturing

Presently, the all-aluminum tailcone is manufactured from aluminum bar stock which is manually fed to a computer numeric controlled (CNC) mill and machined down to close-tolerance (figure 4). The estimated machining time for these parts is about 5 hr followed by surface-finishing operations. Extrusion-compression molding of LFTs was chosen as the manufacturing process in this study, since it met the requirements of low cycle time and retention of fiber integrity during processing.

A single-cavity steel tool was developed for the compression molding of the LFT thermoplastic tailcone. The tool was designed to have enough flexibility that would allow some changes in the design without major tooling re-engineering. The conceptual schematic for molding the plastic tailcone is presented in figure 4. A four-component, compression-molding tool featured a top lid, an interchangeable block, a cap, and a solid cavity. The solid female tool includes the external geometry of the tailcone and the spin grooves. The interchangeable block allows for the manufacturing of a hollow-back tailcone or solid-back tailcone, depending on the desired shape. The cap allows for insert positioning previous to the molding and facilitates the demolding

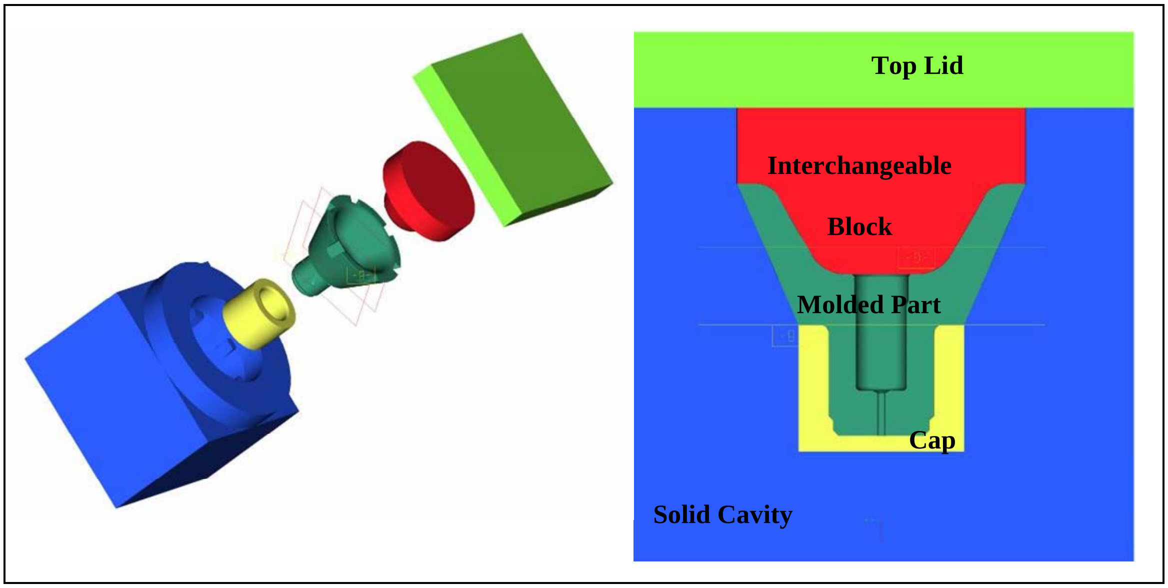

Figure 4. Molding concept for manufacturing of plastic tailcones: (a) exploded view and (b) cross section.

operation. This cap includes the inner threads that assemble to the back of the KE projectile. The molten charge is placed in the solid cavity and formed by the pressure exerted during closing of the press to the final shape.

An internal insert made of steel was used in order to adapt the existing threads of the aluminum tailcone. Several insert designs were considered, and two final concepts were chosen for the molding trials. Two insert configurations were used; a fully threaded insert and a partially threaded beaded insert. The cross-sectional view of the LFT tailcone with the two types of inserts (for the case of the hollow-back tailcone) is shown in figure 5.

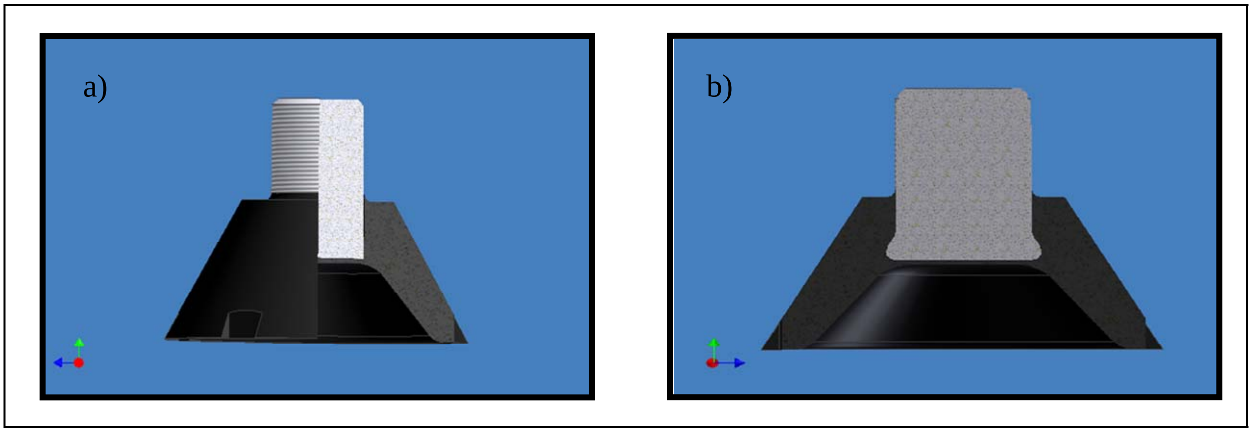

Figure 5. Cross section of LFT composite tailcone showing detail on inserts used during molding trials of hollow-back thermoplastic composite tailcones: (a) threaded insert and (b) beaded insert.

Straight-threaded aluminum inserts, 95 and 100 mm long, were used when molding the back-filled LFT composite tailcone. The cross section of the back-filled tailcone solid model is shown in figure 6.

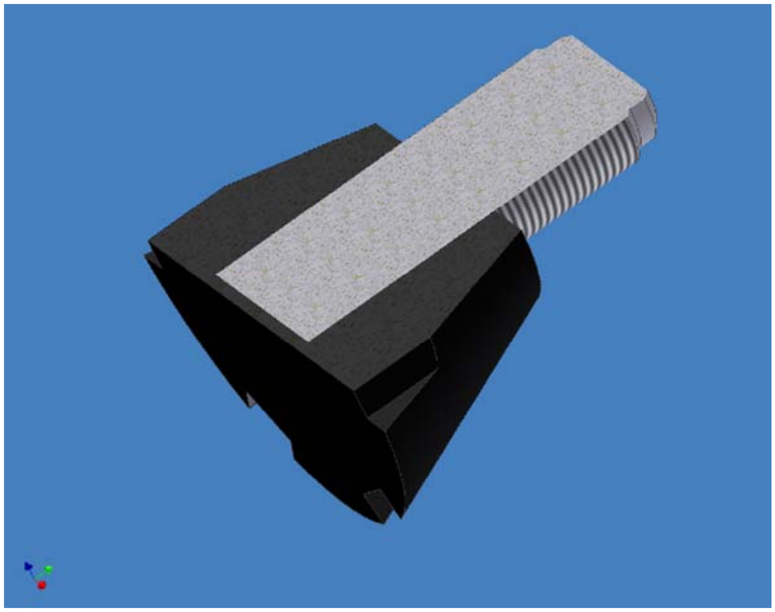

Figure 6. Back-filled LFT composite tailcone cross section.

5. Molding

A 400,000 kg (400 metric ton) press was used to mold the LFT composite tailcone. The initial set of tail cones was molded using nylon 66/E-glass LFT with 40% W_f (table 1). The second set of tail cones was molded using nylon 66/E-glass LFT with 10% W_f. The two fiber loadings represent a high- and low-fiber-loading case respectively, and demonstrate the flexibility of the extrusion-compression molding process. The aluminum insert was screwed to the cap and placed inside the solid cavity of the tool prior to LFT charge placement. The temperature of the bottom cavity of the mold was raised to 121 °C (250 °F). The plasticator was set at 287 °C (550 °F). Once the extruded charge was transferred from the plasticator to the mold, the press was lowered and a 300,000-kg (300-metric-ton) force was applied to consolidate the LFT charge around the insert. The mold was cooled in air and demolded. The manufacturing cycle time was approximately 60 s. The molded nylon LFT 40% W_f thermoplastic composite hollow-back tailcones are shown in figure 7, alongside the all-aluminum tailcone and some of the inserts used in the first molding trials.

Table 1. Physical, mechanical, and thermal properties of nylon 66 (PA) long glass fiber.

Physical Properties	**English**	**Metric**	**ASTM**
Primary additive	50%	50%	—
Specific gravity	1.57	1.57	D 792
Molding shrinkage			
1/8-in (3.2-mm) section	0.0010–0.0030 in/in	0.10%–0.30%	D 955
Mechanical Properties			
Impact strength, Izod			
Notched 1/8-in (3.2-mm) section	5.0 ft-lb/in	267 J/m	D 256
Unnotched 1/8-in (3.2-mm) section	24.0 ft-lb/in	1281 J/m	D 4812
Tensile strength	35000 psi	241 MPa	D 638
Tensile elongation	2.0%–3.0%	2.0%–3.0%	D 638
Tensile modulus	2.50×10^6 psi	17238 MPa	D 638
Flexural strength	50000 psi	345 MPa	D 790
Flexural modulus	2.30×10^6 psi	15858 MPa	D 790
Thermal Properties			
Deflection temperature			
At 264 psi (1820 kPa)	460 °F	238 °C	D 648
At 66 psi (455 kPa)	475 °F	246 °C	D 648

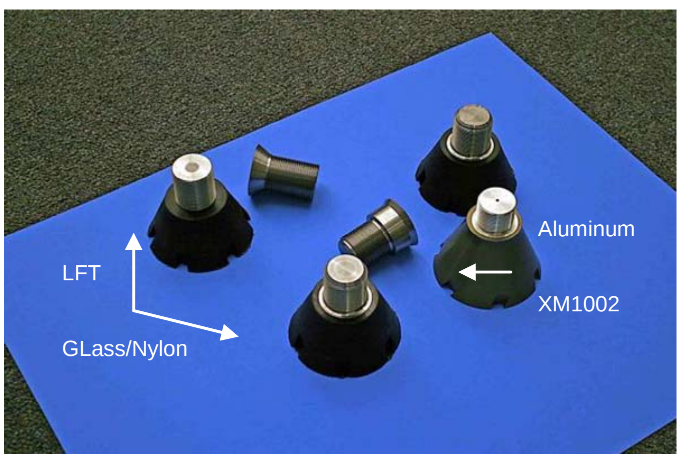

Figure 7. Molded thermoplastic composite tailcone, aluminum inserts, and aluminum tailcone.

The second molding trials were performed using 0% (neat nylon 66), 10%, and 40% W_f LFT pellets under the same processing conditions previously described. The second molding attempt concentrated on the manufacture of the back-filled tailcones. Cost analysis comparing an all-aluminum vs. an LFT composite tailcone as well as microstructural studies were conducted to evaluate the volume fractions, fiber lengths, and fiber orientations developed in the tailcone by burn-off studies (*11*). To minimize the effect of thermal stresses developed during the cooling cycle of the tailcones, moldings were cooled using different cooling rates and under different conditions.

The produced back-filled cones are shown in figure 8. Once they were visually inspected, they were sectioned and polished to assess the quality of the molded parts. The tailcones molded with pure nylon showed severe external cracks induced by the excessive shrinkage of the polymer during the cooling stage (figure 9) and were discarded for any further analysis.

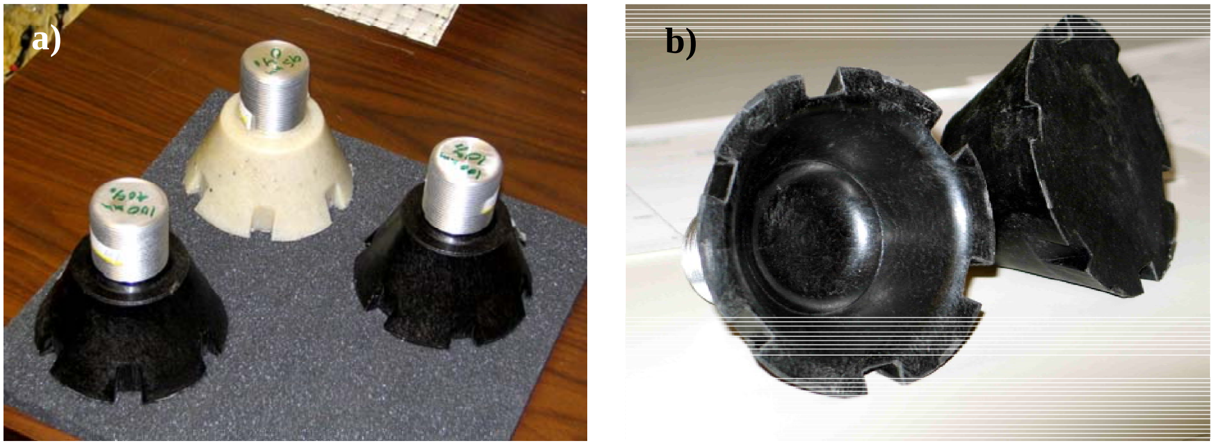

Figure 8. (a) Back-filled cones produced during second molding trials using neat nylon 66 (white cone), 10% (right) and 40% W_f glass LFT (left). (b) Detail showing as produced hollow-back tailcone (first molding) and back-filled version (second molding).

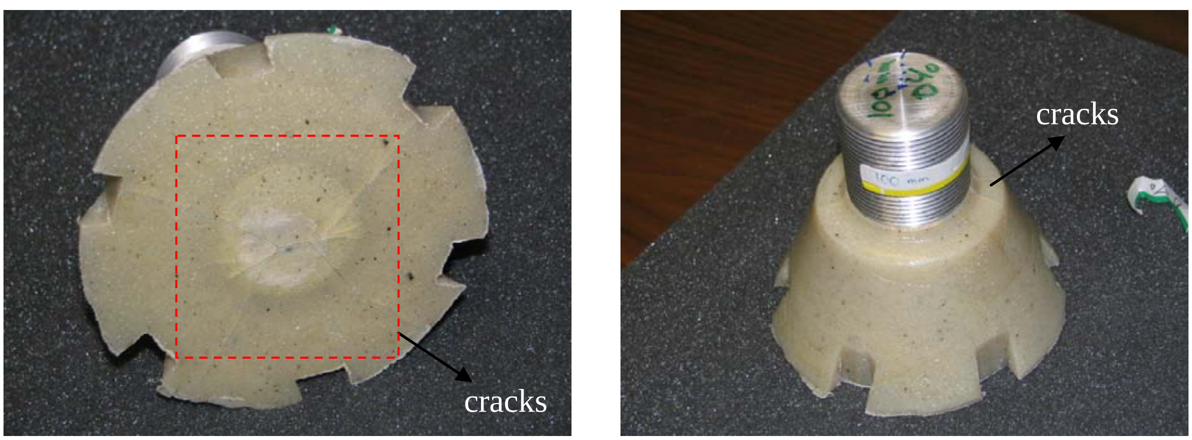

Figure 9. Cross-section image of neat nylon 66 tailcone and detail on thermally induced cracks.

The tailcones molded with a glass fiber loading of 10% W_f showed small signs of warpage. The tailcones molded with 40% W_f did not show any significant signs of processing induced flaws. Once the visual inspection was finished, both the 10% and the 40% W_f loaded cones were sectioned to determine the porosity and the occurrence on internal flaws. The cross-section images for the 10% and 40% moldings are shown in figures 10 and 11. It is clear that the

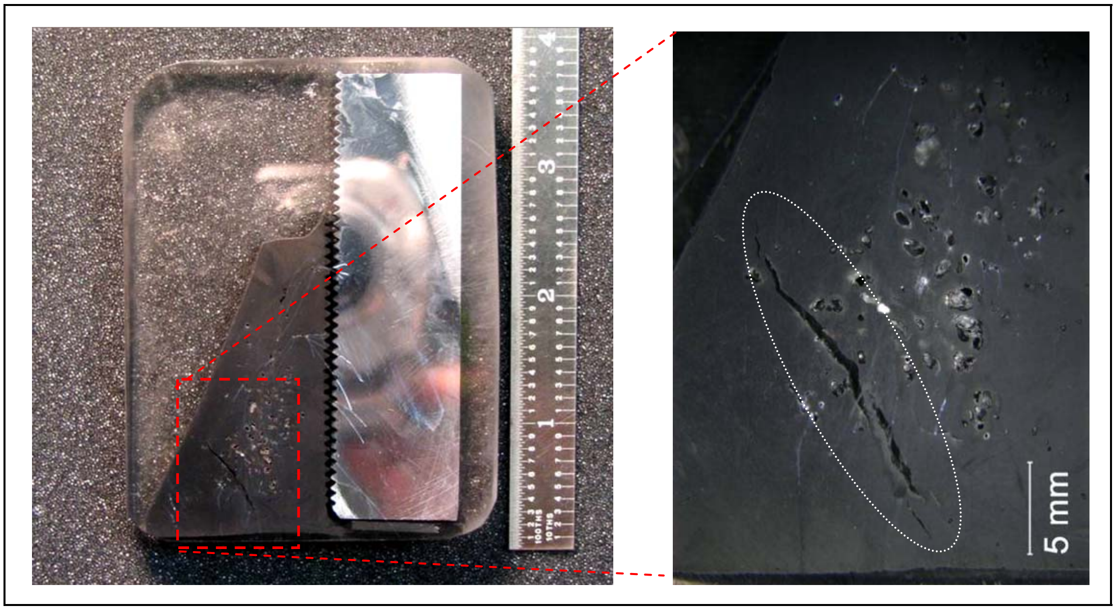

Figure 10. Cross-section image of 10% W_f nylon 66 tailcone and detail on porosity and thermal stress induced crack.

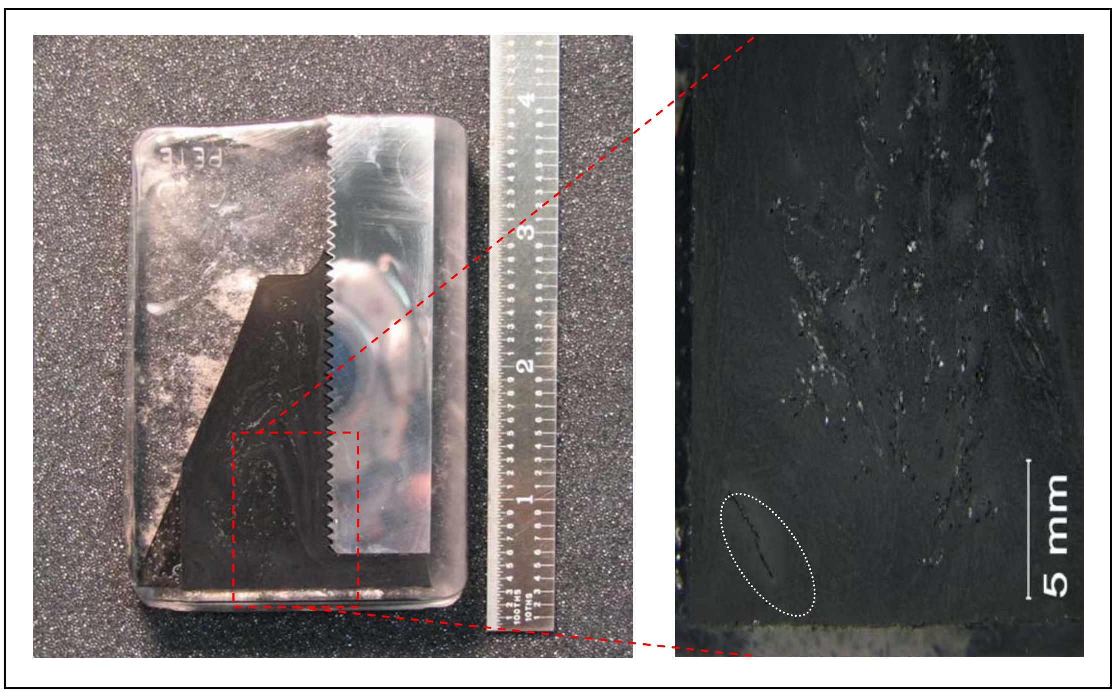

Figure 11. Cross-section image of 40% W_f nylon 66 tailcone and detail on minor crack formation at the edge of the tailcone.

increase in fiber loading on the part restricts the crack formation due to thermal stresses and reduces thermally induced flaws (as the glass fiber content increases, the CTE is lowered). The internal cracks observed on the 10% W_f moldings are highly developed and can affect the

performance of the tailcones significantly during firing. There were some small cracks observed on the 40% moldings, but these are not expected to be a detriment to the structural integrity due to their location and size. To minimize the probability of thermal cracking inside the cones the upper tool temperature was increased and the resident time in the press during cooling was adjusted to 3 min.

6. Summary

Thermoplastic composites can be used effectively in replacing metal components that require extensive machining, such as in the case of an all-aluminum tailcone used in a KE penetrator. Long fiber thermoplastic-composite tailcones with hollow-back and back-filled configuration were manufactured successfully using extrusion-compression molding. Processing issues related to optimum resident time in the press and upper- and lower-tool temperatures were optimized to produce good quality moldings. A projected 230% cost savings is realized in adopting the long fiber thermoplastic tailcone in place of an all-aluminum one, for training round applications. Successful firing trials have been conducted with the 40% LFT filled nylon 66 tailcones; furthermore, the projectiles stabilized by the thermoplastic-composite tailcone hit the desired location in the target.

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